REBOUND-HAMMER ASSESSMENT OF CONCRETE CURED IN SALINE AND BOREHOLE WATER

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ABSTRACT

Saline water is readily available in coastal communities, yet evidence on its suitability for curing concrete remains limited. This study reanalysed rebound-hammer measurements on 150 mm concrete cubes produced with a nominal 1:2:4 mix and a water–cement ratio of 0.60 and cured in borehole water from Otuoke and saline water from Korokorosei, Bayelsa State, Nigeria. Rebound numbers were recorded at 7, 14, 21 and 28 days. Specimen means were recalculated from the individual readings, and the two-curing media were compared using Welch tests with Holm correction, Hedges' g, exact permutation tests, a split-plot analysis of variance and a logarithmic age model. Rebound number increased with age in both media. The saline group was about 13% higher at 7 days, but the difference remained below 2.5% at later ages, and no age-specific difference was significant after correction. Curing age accounted for most of the variation, whereas the interaction between curing medium and age was not statistically significant. An apparent decline in hammer-derived strength at 21 days was traced to an arithmetic error in the computation of the group mean. The findings are constrained by the small number of specimens per group, uncertain independence between specimens across ages, the absence of water-chemistry data and undocumented hammer calibration. The results indicate an early difference in surface hardness but provide no evidence of equivalent compressive strength, durability performance or a confirmed curing-medium effect.

Keywords: Saline water, Rebound number, Concrete curing, Surface hardness, Non-destructive testing, Niger Delta

1.0 INTRODUCTION

Alternative water sources could reduce freshwater demand for concrete production in coastal settlements. Reviews show that the performance of seawater concrete depends on binder composition, dissolved salts, curing conditions and reinforcement (Aghajanzadeh *et al.*, 2026; Ebead *et al.*, 2022; Mohamed *et al.*, 2024; Rathnarajan & Sikora, 2023; Saxena & Baghban, 2023). Local water sources, therefore, need to be characterised before use.

Seawater used for mixing and saline water used for curing represent different conditions. Mixing introduces dissolved salts throughout the fresh paste, whereas immersion exposes hardened concrete only through its external surfaces. Khatibmasjedi *et al.* (2020) and Kumar *et al.* (2025) examined seawater-mixed concrete under different curing regimes, and Nepomuceno *et al.* (2025) evaluated mechanical and time-dependent behaviour during prolonged immersion. These studies show that both the mixing water and the exposure history must be specified when interpreting results.

Responses also cannot be generalised across water sources. Falade *et al.* (2026) tested separate mixing and curing combinations using hypersaline solutions far more concentrated than ordinary seawater. Ouslimane *et al.* (2026) reported reduced early-age compressive strength in permeable, low-cement-content concrete exposed to a marine environment. Karthikeyan and Muthusamy (2026) related mortar behaviour to the chemistry of different coastal seawaters. These conditions differ from the present local comparison and show the importance of measured water chemistry.

Seawater can alter cement hydration and phase development (Li *et al.*, 2020, 2023; Montanari *et al.*, 2019; Parthasarathy *et al.*, 2022; Qu *et al.*, 2021). Chloride binding changes the mineralogy of hydrated cement (Balonis *et al.*, 2010), and external exposure can modify the phase assemblage (Tadesse *et al.*, 2023). These mechanisms could explain differences in rebound number, but the present study did not measure the relevant chemical or microstructural changes.

The test method is equally important. A rebound hammer measures surface hardness rather than the failure load of a specimen. ASTM C805/C805M-18 requires a relationship specific to the concrete under test before strength can be estimated, and it lists surface moisture, finishing and differences between instruments as influences (ASTM International, 2018; Malhotra & Carino, 2004). Calibration studies (Brencich *et al.*, 2013, 2020), experiments on specimen stress and geometry (Brozovský *et al.*, 2019) and regional calibration of high-strength concrete (Chen *et al.*, 2023) show why a generic conversion curve may be unsuitable. ACI 228.1R-19 (ACI Committee 228, 2019) and BS EN 13791:2019 (British Standards Institution, 2019) likewise require a correlation with core or cube strengths before rebound data are used to estimate strength. In seawater exposure, the rebound method underestimated strength after immersion in one study (Celerinos *et al.*, 2023) and overestimated it after splash-zone exposure in another (Celerinos *et al.*, 2024).

This study compares rebound measurements from concrete immersed in Otuoke borehole water and Korokorosei saline water in Bayelsa State, Nigeria. Earlier Nigerian research on salinity examined different mixing and exposure conditions (Akinsola *et al.*, 2012). The objectives were to (i) quantify rebound response and between-specimen dispersion from 7 to 28 days; (ii) compare the two-curing media under explicit statistical assumptions, including the change in their difference with age; and (iii) audit the hammer-derived strength trend reported in the original project report. The study provides a preliminary local comparison and does not validate the use of saline water for construction.

2.0 MATERIALS AND METHODS

2.1 Materials and experimental record

Data provenance. The data reanalysed in this paper were generated in an undergraduate final-year project in the Department of Civil Engineering, Federal University Otuoke, carried out by Enai Tiemo and Anthony Godwin Onyekachukwu in 2024 under the supervision of the first author. Throughout this paper, “the original record” or “the original project report” refers to that project report, which contains the experimental description, the individual rebound readings, the specimen summary tables and the hammer-derived strength values; values described as “supplied” are those reported in it. The project report has not been published in a journal or conference proceedings; it was submitted and examined only as part of the undergraduate degree assessment. The students gave consent for the data to be reanalysed and published. The summary error identified in Section 3.3 therefore concerns the examined project report only; no published version requires correction.

Ordinary Portland cement was obtained near Federal University Otuoke, washed and sieved sand came from Otuoke, and crushed granite had a reported maximum particle size of 20 mm. Cement brand, strength class, aggregate grading and moisture content were not documented.

Borehole water was obtained in Otuoke. The second source was described as saline water collected from the coastal area of Korokorosei Town in the Southern Ijaw Local Government Area. The record describes tests for pH, conductivity, total dissolved solids, salinity and turbidity, but the results table is empty. "Saline water" is therefore a description of the source; its salinity and its chloride, sulphate and magnesium contents are unknown. Borehole water served as the reference medium, but its compliance with BS EN 1008 (BSI, 2002) was not verified. Those standard addresses mixing rather than curing water; they accept potable water without testing, require groundwater to be tested, and consider seawater suitable only for unreinforced concrete. The source of the mixing water was not stated.

2.2 Mixture and specimen preparation

The original record specified a nominal cement–sand–coarse aggregate ratio of 1:2:4 and a water–cement ratio of 0.60. The methods describe batching by mass, but the appendix allocates volumes and converts them to masses using bulk densities of 1440, 1600 and 1700 kg/m³. The listed quantities for six cubes are 7.19 kg of cement, 14.50 kg of sand, 30.91 kg of granite and 4.31 kg of water. These quantities imply about 1:2.02:4.30 by mass and include a 10% cement allowance, the use of which in the actual batch is unclear. The nominal ratio is reported as intended, not as verified.

Concrete was placed in oiled steel moulds measuring 150 × 150 × 150 mm, compacted in three layers, with 25 strokes per layer. After 24 hours, the specimens were demoulded and immersed in their designated water. Borehole-water specimens were labelled D1–D3 and saline-water specimens S1–S3, and readings were reported at 7, 14, 21 and 28 days. The record mentions six cubes in total, which suggests that the same cubes were tested at every age, but it also describes three specimens per group at each age. Because this is not resolved, independence across ages is not assumed.

2.3 Rebound measurements and strength estimates

The original record cites BS 1881-202:1986 (BSI, 1986) as its test reference. That standard has been withdrawn and replaced by BS EN 12504-2 (BSI, 2021). Eight impacts were recorded on each specimen at each age, giving 24 readings per curing medium and age; this is fewer than the minimum of nine readings in BS EN 12504-2 and the ten readings in ASTM C805/C805M-18 (ASTM International, 2018). The record states no rule for discarding outlying readings, and none was applied in this reanalysis: all eight readings were retained in every specimen mean. The time between removal of the cubes from the curing water and testing was not recorded, so the surface-moisture condition at testing is unknown. Hammer type, impact energy, impact direction, calibration checks, specimen restraint, impact spacing and surface preparation were also not documented, so procedural compliance cannot be verified. ASTM C805/C805M-18 is used here only to interpret rebound measurements; it was not the procedure followed in the original experiment.

The original tables give specimen rebound averages and values labelled compressive strength. No destructive compression results or rebound–strength equations are supplied. The individual readings are the primary data. The supplied strength values are retained as unvalidated hammer-derived estimates, and no assumed correction curve is applied. The original M15 description is treated as a nominal target, not an achieved strength class.

2.4 Descriptive analysis

Specimen averages were recalculated from the eight readings. For curing medium k, specimen i and age t, the specimen mean was calculated using Equation (1).

$$R_{ki}(t) = \frac{1}{m}\sum_{j=1}^{m} R_{kij}(t) \quad (1)$$

Here, $R_{ki}(t)$ is the mean rebound number of specimens i in medium k at age t; $R_{kij}(t)$ is reading j on that specimen; $m = 8$ is the number of readings per specimen; $i = 1, 2, 3$ identifies the labelled specimens; $k = \mathrm{B}$ denotes borehole water and $k = \mathrm{S}$ denotes saline water; and t is the curing age in days. Rebound number is dimensionless.

The group mean and the sample standard deviation of the three-specimen means were calculated using Equations (2) and (3).

$$\overline{R}_k(t) = \frac{1}{n}\sum_{i=1}^{n} R_{ki}(t) \quad (2)$$

$$s_k(t) = \sqrt{\frac{\sum_{i=1}^{n}\left[R_{ki}(t) - \overline{R}_k(t)\right]^2}{n-1}} \quad (3)$$

Here, $\bar{R}_k(t)$ is the group mean rebound number; $s_k(t)$ is the sample standard deviation of the specimen means; and $n = 3$ is the number of labelled specimens per medium and age. Other terms are defined as in Equation (1). The standard deviation describes dispersion between specimens; it does not represent calibration uncertainty.

The relative difference between saline and borehole curing, and the percentage increase within each group from 7 to 28 days, were calculated using Equations (4) and (5).

$$\Delta_R(t) = 100 \times \frac{\overline{R}_{\mathrm{S}}(t) - \overline{R}_{\mathrm{B}}(t)}{\overline{R}_{\mathrm{B}}(t)} \quad (4)$$

$$G_k = 100 \times \frac{\overline{R}_k(28) - \overline{R}_k(7)}{\overline{R}_k(7)} \quad (5)$$

Here, $\Delta_R(t)$ is the relative group difference (%); $\bar{R}_{\mathrm{S}}(t)$ and $\bar{R}_{\mathrm{B}}(t)$ are the saline and borehole group means, respectively; G_k is the percentage increase in the group mean between 7 and 28 days; and $\bar{R}_k(7)$ and $\bar{R}_k(28)$ are the group means at those ages. A positive Δ_R indicates a higher saline response. G_k is an endpoint comparison, not a model of hydration or strength development.

The supplied hammer-derived strength estimates were averaged using Equation (6).

$$\overline{f}_{\mathrm{est},k}(t) = \frac{1}{n}\sum_{i=1}^{n} f_{\mathrm{est},ki}(t) \quad (6)$$

Here, $\bar{f}_{\mathrm{est},k}(t)$ is the group mean of the supplied strength estimates (MPa); $f_{\mathrm{est},ki}(t)$ is the supplied estimate for specimen i in medium k at age t; and the subscript "est" denotes an estimated value. Equation (6) only averages the existing estimates; it does not convert the corrected rebound numbers into strength (1 MPa = 1 N/mm²).

All calculations used unrounded values. The eight impacts on each cube were treated as subsamples rather than independent specimens. Descriptive statistics are the primary analysis; the comparisons in Sections 2.5

and 2.6 are conditional sensitivity analyses for the reasons given in Section 5.0. Analyses were carried out in Python 3 using NumPy and SciPy, and all reported statistics were derived from the specimen means in Table 1.

2.5 Age-specific comparisons

At each age, a two-sided Welch comparison (Welch, 1947) was applied to the three specimen means per medium. The test allows unequal variances but assumes independent, approximately normally distributed specimen means; neither assumption can be checked with three specimens (Section 5.0). The standard error, Welch statistic, degrees of freedom and confidence interval were calculated using Equations (7)–(10). The age argument t is omitted from Equations (7)–(13) for readability; each quantity is calculated separately at each age.

$$SE_d = \sqrt{\frac{s_S^2}{n_S} + \frac{s_B^2}{n_B}} \tag{7}$$

$$T_W = \frac{d}{SE_d} \tag{8}$$

$$\nu = \frac{\left(\frac{s_S^2}{n_S} + \frac{s_B^2}{n_B}\right)^2}{\frac{\left(\frac{s_S^2}{n_S}\right)^2}{n_S - 1} + \frac{\left(\frac{s_B^2}{n_B}\right)^2}{n_B - 1}} \tag{9}$$

$$\mathrm{CI}_{95\%} = d \pm t_{0.975,\nu} \times SE_d \tag{10}$$

Here, $d = \bar{R}_S - \bar{R}_B$ is the saline-minus-borehole mean difference (rebound units); SE_d is its standard error; s_S and s_B are the sample standard deviations of the specimen means; $n_S = n_B = 3$ are the numbers of specimens; T_W is the dimensionless Welch statistic; ν is the Welch–Satterthwaite degrees of freedom; $\mathrm{CI}_{95\%}$ gives the lower and upper limits of the unadjusted 95% confidence interval for d; and $t_{0.975,\nu}$ is the 97.5th percentile of Student's t distribution with ν degrees of freedom. The two-sided p-value is twice the upper-tail probability beyond $|T_W|$.

The four age-specific p-values were adjusted by Holm's step-down procedure (Holm, 1979) using Equation (11), with a family-wise significance level $\alpha = 0.05$.

$$p_{\mathrm{adj},(r)} = \min\left\{1, \max_{u \le r}(m_c - u + 1)p_{(u)}\right\} \tag{11}$$

Here, $p_{(u)}$ is the uth smallest unadjusted p-value; r and u are ranks (1 to m_c); $m_c = 4$ is the number of comparisons; and $p_{\mathrm{adj},(r)}$ is the adjusted p-value at rank r. The procedure remains valid even when comparisons are dependent. Confidence intervals were not adjusted for simultaneous coverage.

Standardised differences were expressed as Hedges' g with the exact small-sample correction (Lakens, 2013), using Equations (12) and (13). Between-specimen dispersion relative to the mean was expressed as the coefficient of variation (Equation 14).

$$g = J \times \frac{d}{s_{\mathrm{p}}}, \quad J = \frac{\Gamma\left(\frac{\mathrm{df_p}}{2}\right)}{\sqrt{\frac{\mathrm{df_p}}{2}} \times \Gamma\left(\frac{\mathrm{df_p}-1}{2}\right)} \tag{12}$$

$$s_{\mathrm{p}} = \sqrt{\frac{(n_{\mathrm{S}}-1)s_{\mathrm{S}}^2 + (n_{\mathrm{B}}-1)s_{\mathrm{B}}^2}{n_{\mathrm{S}}+n_{\mathrm{B}}-2}} \tag{13}$$

$$\mathrm{CV}_k = 100 \times \frac{s_k}{\bar{R}_k} \tag{14}$$

Here, g is the dimensionless standardised mean difference; s_{p} is the pooled standard deviation of the specimen means, used only to scale the effect; J is the bias-correction factor ($J = 0.80$ for these data); $\mathrm{df_p} = n_{\mathrm{S}} + n_{\mathrm{B}} - 2 = 4$ is the pooled degrees of freedom; Γ is the gamma function; and CV_k is the coefficient of variation (%) of group k. A positive g indicates a higher saline mean. Pooling for this descriptive effect size does not replace the unequal-variance Welch test, and large g values arising from very small dispersions should not be read as precise engineering effects.

An exact permutation test enumerated all 20 ways of allocating the six specimen means at each age into two groups of three. Its two-sided p-value was calculated using Equation (15).

$$p_{\mathrm{perm}} = \frac{1}{20}\sum_{a=1}^{20} I(|d_a| \geq |d_{\mathrm{obs}}|) \tag{15}$$

Here, p_{perm} is the permutation p-value; d_a is the mean difference for allocation a; d_{obs} is the observed difference; and $I(\cdot)$ equals 1 when the condition is true and 0 otherwise. The test assumes that specimens are exchangeable under the null hypothesis. Because each allocation has a complementary allocation with the same absolute difference, the smallest attainable p-value is 0.10, which limits what six observations can show. Normality and equal-variance pretests were not used to choose tests; no observations were removed, and no test was applied to the undocumented strength conversions.

2.6 Medium–age interaction and age trend

To test whether the saline–borehole difference changed with age, a mixed (split-plot) analysis of variance (ANOVA) was applied to the 24 specimen means, with curing medium as the between-specimen factor and age as the within-specimen factor. This model matches the six-cube reading of the record, in which each labelled cube was tested at every age. Departure from sphericity was corrected with the Greenhouse–Geisser factor (Greenhouse & Geisser, 1959). A two-way ANOVA that treats all 24 specimen means as independent was run as an alternative, matching the reading that separate cubes were tested at each age. Effect size was expressed as partial eta squared, Equation (16).

$$\eta_{\mathrm{p}}^2 = \frac{SS_{\mathrm{effect}}}{SS_{\mathrm{effect}} + SS_{\mathrm{error}}} \tag{16}$$

Here, η_{p}^2 is partial eta squared; SS_{effect} is the sum of squares of the tested effect (medium, age or medium × age); and SS_{error} is the sum of squares of the error term used for that effect in the F test.

The age trend in each medium was described by Equation (17), which was fitted by least squares to the 12 specimen means for each medium.

$$R_{ki}(t) = a_k + b_k \ln t + e_{ki}(t) \tag{17}$$

Here, a_k is the intercept (the fitted rebound number at $t = 1$ day); b_k is the slope, that is, the change in rebound number per unit increase in ln t; ln t is the natural logarithm of age in days; and $e_{ki}(t)$ is the residual. The slopes were compared using a medium × ln t interaction term in a combined model. The logarithmic form is an empirical description of the 7–28-day range and is not used for extrapolation. If the same cubes were tested repeatedly, the regression standard errors are underestimated.

3.0 RESULTS

3.1 Recalculated specimen rebound numbers

Table 1 presents the specimen means recalculated from the original readings. Every labelled specimen had a higher mean at each successive age. The corrected 28-day mean of D2 is 18.75, compared with 18.50 in the original project report; all group statistics and figures use the corrected value.

Table 1: Recalculated specimens mean rebound numbers

Age (days)	D1	D2	D3	S1	S2	S3
7	11.875	13.125	12.688	14.125	14.875	13.500
14	17.250	17.875	17.000	15.938	18.250	17.375
21	18.000	18.000	18.500	18.500	18.500	18.500
28	19.500	18.750	19.500	19.000	20.000	20.000

D and S denote borehole-water and saline-water specimens, respectively. Each value is the mean of eight readings. Three decimal places are retained for reproducibility and do not imply instrument precision.

3.2 Group response and relative difference

At 7 days, the saline mean (14.17) exceeded the borehole mean (12.56) by 1.60 rebound units (Table 2; Figure 1). At 14 days, the saline mean was slightly lower, and at 21 and 28 days, it was higher by less than half a rebound unit. The data therefore show an early separation followed by closely similar responses (Figure 2), not a consistent saline advantage.

Table 2**:** Group rebound response and relative difference

Age (days)	Borehole mean ± SD	Saline mean ± SD	Difference (units)	Relative difference (%)
7	12.56 ± 0.63	14.17 ± 0.69	+1.60	+12.77
14	17.38 ± 0.45	17.19 ± 1.17	−0.19	−1.08
21	18.17 ± 0.29	18.50 ± 0.00	+0.33	+1.83
28	19.25 ± 0.43	19.67 ± 0.58	+0.42	+2.16

SD is the sample standard deviation of three specimen means. Relative difference uses the borehole mean as the denominator (Equation 4). Rebound numbers and their SDs are dimensionless.

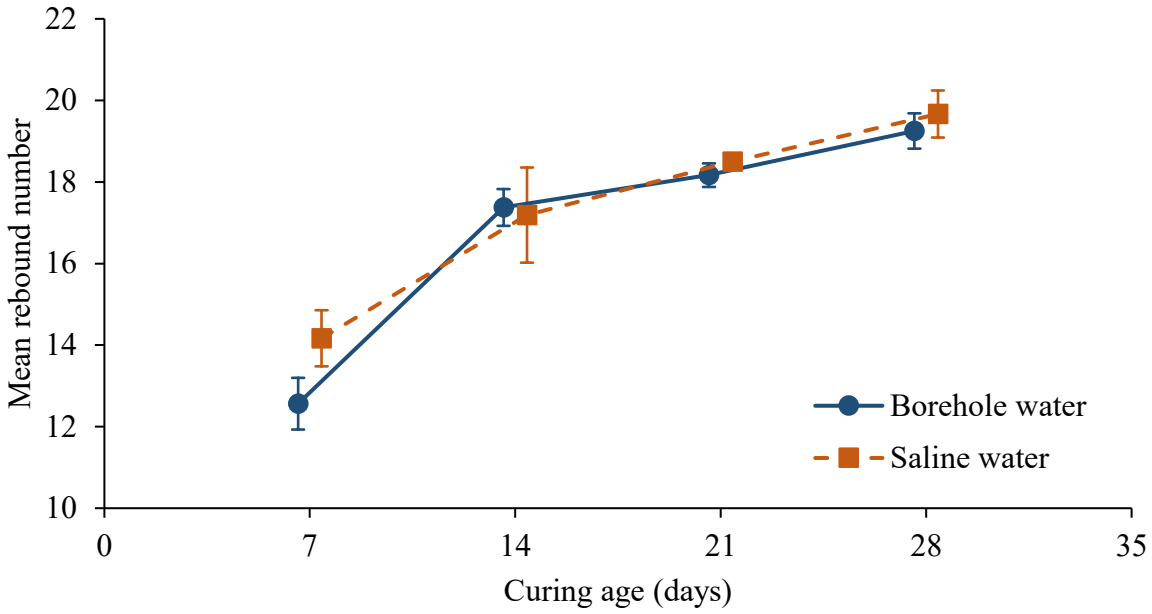


Figure 1: Mean rebound number at each curing age. Error bars show ±1 sample SD of three specimen means. Points are offset horizontally by ±0.4 days for clarity; lines join observations and are not fitted models.

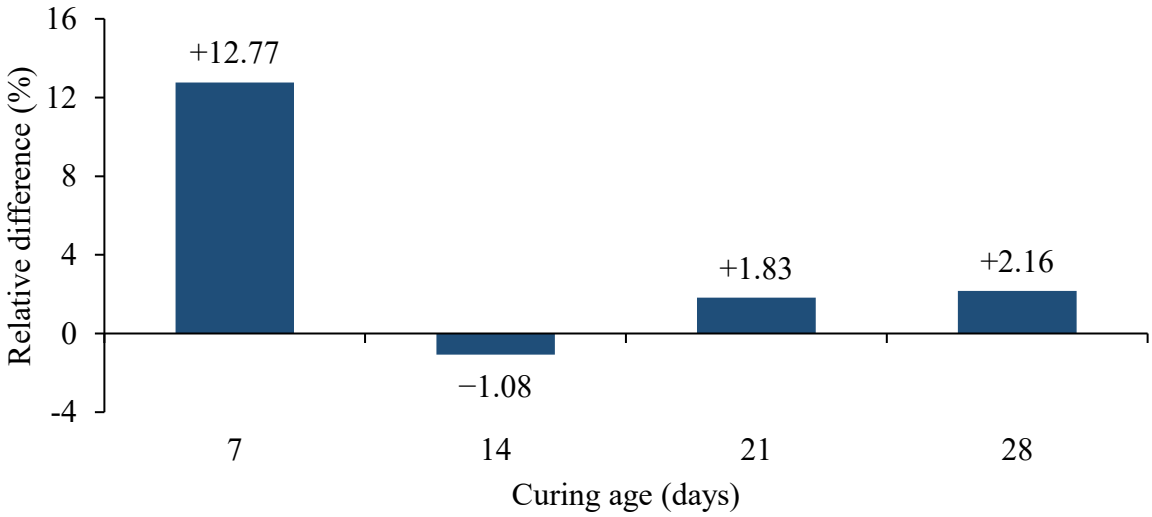


Figure 2: Relative difference in mean rebound number between saline and borehole curing. Borehole water is the denominator; positive values indicate a higher saline mean.

Between 7 and 28 days, the borehole mean increased by 6.69 units (53.23%) and the saline mean by 5.50 units (38.82%). The larger percentage increase in the borehole group partly reflects its lower starting value.
The greatest between-specimen dispersion occurred in the saline group at 14 days (SD = 1.17; specimen means ranged from 15.94 to 18.25). At 21 days, all three saline specimen means were 18.50. Individual readings still varied, so the zero SD at that age reflects equal specimen averages rather than an absence of measurement variation.

3.3 Audit of hammer-derived strength estimates

The 21-day borehole summary in the original project report was 10.02 MPa, whereas the corresponding specimen estimates were 14.22, 14.22, and 14.62 MPa, with an average of 14.35 MPa. The apparent decline

in strength discussed in the original record was therefore a summary error. Table 3 corrects the arithmetic while retaining the supplied specimen estimates.

Table 3: Group means of the supplied hammer-derived strength estimates

Age (days)	Borehole estimate (MPa)	Saline estimate (MPa)	Relative difference (%)
7	9.89	11.20	+13.28
14	13.79	13.61	−1.31
21	14.35	14.62	+1.86
28	15.01	15.54	+3.49

Values are means of the supplied estimates, not direct compression results or estimates recalculated from the corrected rebound numbers. Relative differences were calculated from unrounded means and may differ slightly from values calculated from the rounded means shown.

At 28 days, the original D2 estimate was 14.22 MPa, despite a corrected rebound average of 18.75; the same estimate was assigned to a rebound number of 18.0 in the 21-day table. Without the conversion chart or calibration records, a corrected D2 strength cannot be established. The 28-day means of 15.01 and 15.54 MPa are therefore reported for traceability only, and their 3.49% difference is not evidence of a measured strength gain.

3.4 Age-specific statistical comparisons

Table 4: Conditional Welch comparisons of specimen mean rebound numbers

Age (days)	T_W	v	95% CI for d	Welch p	Holm p
7	2.97	3.97	+0.10 to +3.11	0.04	0.17
14	−0.26	2.58	−2.71 to +2.34	0.81	0.81
21	2.00	2.00	−0.38 to +1.05	0.18	0.55
28	1.00	3.71	−0.78 to +1.61	0.38	0.76

d is the saline-minus-borehole difference in mean rebound number; T_W is the Welch statistic; v is its degrees of freedom. Confidence intervals are unadjusted and in rebound units. Both p-values are two-sided; the Holm-adjusted p-value accounts for the four age comparisons. Each comparison uses three specimen means per group and requires the assumptions in Section 2.5.

At 7 days, the unadjusted interval excluded zero (Welch $p = 0.04$), but the Holm-adjusted p-value was 0.17, and no comparison met the family-wise threshold of 0.05 (Table 4). The 28-day interval (−0.78 to +1.61 rebound units) included effects in either direction. Failure to detect a difference is not evidence of equivalence.

Table 5: Effect sizes, dispersion and exact permutation tests

Age (days)	Hedges' *g*	Borehole CV (%)	Saline CV (%)	Exact permutation *p*
7	+1.93	5.05	4.86	0.10
14	−0.17	2.59	6.79	0.90
21	+1.30	1.59	0.00	0.40
28	+0.65	2.25	2.94	0.50

CV is the coefficient of variation of the specimen means (Equation 14). A positive *g* indicates a higher saline mean. Exact *p*-values enumerate all 20 allocations, assume exchangeability and are unadjusted. The zero-saline CV at 21 days reflects identical specimen averages, not identical readings.

At 21 days, $g = 1.30$ accompanied a raw difference of only 0.33 units and a zero saline SD, which shows how sensitive, standardised effects are to very small dispersions. No exact permutation *p*-value reached 0.05 (Table 5); the 7-day value of 0.10 is the smallest attainable. The unadjusted 7-day Welch result thus depends on the assumptions stated in Section 2.5.

3.5 Medium–age interaction and age trend

Table 6: Analysis of variance of specimen mean rebound numbers

Model	Source	df	*F*	*p*	η_p^2
Mixed (split-plot)	Medium	1, 4	3.10	0.15	0.44
	Age	3, 12	132.27	< 0.001	0.97
	Medium × age	3, 12	2.70	0.09 (0.12)	0.40
Two-way (independent)	Medium	1, 16	4.62	< 0.05	0.22
	Age	3, 16	110.64	< 0.001	0.95
	Medium × age	3, 16	2.26	0.12	0.30

df gives the degrees of freedom for the effect and error. The value in parentheses is the Greenhouse–Geisser-corrected *p*-value ($\varepsilon = 0.69$); the corrected *p*-value for age remained < 0.001. The mixed model assumes the same six cubes were tested at every age; the two-way model assumes separate cubes at each age. Both analyses are conditional.

Age accounted for most of the variation in both models ($\eta_p^2 \geq 0.95$; Table 6). In the mixed model, neither the medium effect ($p = 0.15$) nor the medium × age interaction (Greenhouse–Geisser $p = 0.12$) was significant. When all specimen means were treated as independent, the medium effect reached $p < 0.05$, but this model ignores probable repeated testing and is driven by the same 7-day difference identified in Table 4. The interaction was not significant in either model, so the early separation and later convergence cannot be distinguished from random variation. However, statistical power to detect such a pattern is low.

Equation (17) described the age trend closely, with $R^2 = 0.92$ for both media on specimen means. The fitted slope b_k was 4.77 rebound units per unit ln *t* (95% CI 3.80 to 5.74) for borehole curing and 3.94 (95% CI 3.11 to 4.77) for saline curing, with intercepts of 3.76 and 6.60, respectively. The slope difference of −0.84 (95%

CI −2.03 to 0.36; $p = 0.16$) was not significant. The flatter saline slope is consistent with its higher 7-day value and similar 28-day value.

4.0 DISCUSSION

4.1 What the early saline response indicates

The higher saline rebound number at 7 days is consistent with an early difference in surface hardness. Studies of cementitious systems containing seawater describe changes in hydration and mechanical behaviour (Li *et al.*, 2020, 2023; Montanari *et al.*, 2019; Parthasarathy *et al.*, 2022; Qu *et al.*, 2021), and chloride interactions with hydrated cement minerals (Balonis *et al.*, 2010) and phase changes during seawater exposure (Tadesse *et al.*, 2023) could affect the near-surface material. However, those studies mostly concern mixing water, and no hydration, phase, microstructural or water-chemistry measurements are available here. The present difference, therefore, cannot be attributed to chloride acceleration, sulphate reactions or a particular salt concentration.

Surface moisture is a competing explanation. ASTM C805/C805M-18 (ASTM International, 2018) and Malhotra and Carino (2004) identify surface moisture and finishing as influences on rebound number. Because the time between removal from water and testing, and the surface preparation, are absent from the record, the two groups may not have been tested under equivalent surface conditions. Consequently, the observed difference cannot be assigned solely to a material effect of saline curing.

4.2 Comparison with recent strength studies

The smaller differences after 7 days, the non-significant medium × age interaction and the similar logarithmic slopes indicate that the initial separation was not sustained. Rebound differences should not be compared directly with published compressive-strength percentages. Kumar *et al.* (2025) observed an early strength benefit followed by lower later-age values for seawater-mixed concrete under specific curing regimes, but their mixtures and measurements differ from those of this study; thus, the similar timing does not establish a shared mechanism.

Other experiments show different patterns. Khatibmasjedi *et al.* (2020) found favourable performance of seawater-mixed concrete under several exposure regimes, Nepomuceno *et al.* (2025) evaluated behaviour over 2.5 years of immersion, and Ouslimane *et al.* (2026) reported an early decline in compressive strength for permeable concrete under marine exposure. Together, these results show that exposure duration, mixture and test method all matter; they do not support a general claim that saline water increases or decreases concrete strength. Falade *et al.* (2026) separated freshwater and hypersaline mixing–curing combinations, which offer a useful design for future local experiments, although their concentrated solutions do not represent the unmeasured Korokorosei water. The source comparisons of Karthikeyan and Muthusamy (2026) likewise support source-specific chemical analysis.

4.3 Why the rebound response is insufficient for strength equivalence

A higher rebound number indicates a different surface response under the test conditions; it is not a proportional measure of compressive strength. Brencich *et al.* (2013, 2020) identified substantial calibration uncertainty, and Brozovský *et al.* (2019) showed effects of specimen stress and test-surface geometry. Chen *et al.* (2023) developed curves for specific high-strength concretes and hammer energies, which should not be transferred to these nominally lower-strength cubes. Celerinos *et al.* (2023, 2024) reported opposite directions of estimation bias after immersion and splash-zone exposure. This variation supports calibration against cores

or cubes of the same concrete, as required by ACI 228.1R-19 (ACI Committee 228, 2019) and BS EN 13791:2019 (BSI, 2019), rather than a universal correction for marine exposure.

At 28 days, the difference was 0.42 rebound units. ASTM C805/C805M-18 notes that nominally similar hammers may differ by 1 to 3 units (ASTM International, 2018); this is context, not an uncertainty estimate for the present experiment. Establishing engineering equivalence would require a predefined practical margin, adequate independent replication and validated compression tests.

5.0 LIMITATIONS OF THE STUDY

The limitations below apply to all results in this paper. They are stated in full here, and earlier sections refer to this list rather than repeating it.

(1) *Secondary data:* the analysis relies on a single undergraduate project report. Cement brand and strength class, aggregate grading and moisture content, the source of the mixing water and the proportions batched were not documented.

(2) *Small sample and uncertain independence:* each medium had three labelled specimens per age from a single, unreplicated batch, and the record does not establish whether the same six cubes were tested at every age. Statistical power is therefore low, shared batch effects may make the intervals too narrow, and all inferential results are conditional.

(3) *Unmeasured water chemistry:* the salinity and the chloride, sulphate and magnesium contents of the Korokorosei water, and the quality of the borehole water, were not measured, so no effect can be linked to a particular salt concentration or mechanism.

(4) *Undocumented test procedure:* only eight impacts were recorded per specimen, no discard rule was applied, and the hammer type, impact energy, calibration checks, impact direction and spacing, specimen restraint, surface preparation and the time between removal from water and testing were not recorded. The confidence intervals exclude hammer calibration uncertainty, and differences in surface moisture cannot be ruled out.

(5) *Unvalidated strength estimates:* no destructive compression results, conversion chart or rebound–strength calibration were available, so the hammer-derived strengths are reported for traceability only and cannot be corrected.

(6) *Short observation period:* only ages from 7 to 28 days were tested, and no durability or reinforcement-corrosion data were collected, so long-term performance cannot be inferred.

6.0 CONCLUSIONS

Within the reported local materials and the 7–28-day observation period, the following conclusions are supported:

(1) Mean rebound number increased with age in both media, from 12.56 to 19.25 under borehole curing and from 14.17 to 19.67 under saline curing; age explained most of the variation ($\eta_p^2 \geq 0.95$).

(2) The saline mean was 12.77% higher at 7 days but within −1.08% to +2.16% of the borehole mean at 14–28 days; a consistent saline advantage was not observed.

(3) Under conditional assumptions, no age-specific comparison remained significant after Holm correction, and neither the medium × age interaction nor the difference in logarithmic slopes was significant. These results do not establish equivalence.

(4) The 21-day borehole strength summary in the original project report was erroneous: its specimen estimates average 14.35 MPa, not 10.02 MPa, which removes the apparent decline.

(5) Given the limitations listed in Section 5.0, the dataset supports only a preliminary comparison of surface hardness. Direct compression testing, measured water chemistry, documented hammer calibration and independent batch replication are needed before strength class, durability or suitability for construction can be assessed.

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